TRAINING INTERVENTIONS TO REDUCE AIR FORCE PREDATOR MISHAPS

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The use of unmanned aerial systems (UASs) is expanding rapidly. In military operations, this increased use was often accompanied by relatively high mishap rates compared with rates across more mature manned aircraft. These higher rates led to multiple high-level reviews of unmanned operations to understand the issues, but surprisingly little consensus emerged across reports regarding root causes. To help close this gap, Air Force Predator Class A mishap reports through FY 2006 were analyzed in detail. Mishap rates, counts, and causal factors were all found to shift systematically over time, with a rise in mishap reports citing shortfalls in several skill and knowledge areas in FY 2004-2006. Individual and team Predator training objectives were revisited and the content of crew resource management (CRM) training was refocused on improving these key operator skills. In FY 2007-2008, Predator Class A mishaps attributed to operator error decreased despite increasing numbers of mishaps overall.

While early attempts to use UASs for military purposes can be traced back to World War II or before (Gambone, 2002), unmanned technology clearly entered the mainstream of combat operations during the recent conflicts in Kosovo, Afghanistan, and Iraq. In these conflicts, UASs were first used as Intelligence, Surveillance, and Reconnaissance/Target Acquisition assets, providing commanders with imagery intelligence, electronic intelligence, and streaming video. Resulting information could be used to monitor enemy movements and conduct battle damage assessment. The Predator system added a strike capability, and similar capabilities were not far behind in other Department of Defense (DoD) UAVs. Across all United States military services, the use of unmanned aerial systems (UASs) is expanding rapidly. Predators alone already account for 5% of all Air Force flying hours in FY 2008 (Air Force Safety Center, 2009). Despite the rapid rise of flying hours to date, only about one half of requests for UAS surveillance can currently be met, with growth in flying hours being limited by the ability to train enough crews to meet the demand for battlefield surveillance. The Air Force now flies 27 round-the-clock Predator and Reaper orbits in the Central Command area of operation, which involves 450 pilots. Service leaders want 50 orbits to be flown by 2012, which will require 1,100 pilots (Hoffman, 2008). The Quadrennial Defense Review predicted that approximately 45% of the future long-range strike force will be unmanned (Office of the Secretary of Defense, 2006). Emerging roles for UAVs include homeland security (e.g., border patrol), long-duration law enforcement surveillance, and delivery of critical medical supplies needed on the battlefield (Bone and Balkcom, 2003).

This rapid rise in UAV employment was unfortunately accompanied by high mishap numbers across all military services. This, in turn, led to several senior reviews to understand the root causes. The Office of the Secretary of Defense published a report on UAV reliability in 2003) that looked at non-weather related mission aborts or cancellations. The “Achilles heels” of UAV platforms appeared to revolve around component quality, redundancy, and maintenance, and concluded that it was critical to improve UAV platforms in these areas because reliability affects affordability, availability, and acceptance. A Defense Science Board Study on Unmanned Aerial vehicles and Uninhabited combat Aerial Vehicles (2004) concluded that UAV programs have not yet expended the resources necessary to fix the root causes leading to mishaps, and that manned-aircraft-like reliability is achievable, but will require substantial additional investment. Tvaryanas, Thompson, and Constable (2005) conducted an in-depth review of UAV mishaps across the United States military services. They reported that, since the inception of the systems in the 1990s through the end of FY 2003, 334 mishaps per 100,000 flying hours had occurred with the Navy/Marine Corps Pioneer, 55 mishaps per 100,000 flying hours had occurred with the Army’s Hunter system, and 32 mishaps per 100,000 flying hours occurred with the Air Force’s Predator system. For comparison purposes,

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14. ABSTRACT
The use of unmanned aerial systems (UASs) is expanding rapidly. In military operations, this increased use was often accompanied by relatively high mishap rates compared with rates across more mature manned aircraft. These higher rates led to multiple high-level reviews of unmanned operations to understand the issues, but surprisingly little consensus emerged across reports regarding root causes. To help close this gap, Air Force Predator Class A mishap reports through FY 2006 were analyzed in detail. Mishap rates, counts, and causal factors were all found to shift systematically over time, with a rise in mishap reports citing shortfalls in several skill and knowledge areas in FY 2004-2006. Individual and team Predator training objectives were revisited and the content of crew resource management (CRM) training was refocused on improving these key operator skills. In FY 2007-2008, Predator Class A mishaps attributed to operator error decreased despite increasing numbers of mishaps overall.

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overall Air Force Class A mishap rates ($1 million damage or fatality) are typically in the low single digit range per 100,000 flying hours (O'Toole, Hughes, & Musselman, 2006).

A recent challenge from the Secretary of Defense to reduce the numbers of preventable mishaps by at least 75% (Rumsfeld, 2006) focused attention on Predator mishap frequencies which accounted for 25% of all Air Force Class A AIB reports (at least $1 million damage or a fatality) in the past two years (FY 2006 and 2007). It should be noted that most manned aircraft are mature systems, while most UAV programs are relatively early in their life cycles, and mishap rates tend to improve with system maturation.

A consistent picture of the problem to be solved has not yet emerged for UAS mishap reduction. Even at basic levels such as the relative contributions of equipment failure versus human error, different analysts reached widely differing conclusions. The Office of the Secretary of Defense Reliability Study (2003) reported that human error represented 16% of all sources of Predator A (MQ-1) system failures and 2% of Predator B (MQ-9) mishaps and the Defense Science Board (2004) reported that 17% of UAS mishaps were attributable to human error. On the other hand, Tvaryanas and his colleagues (2005) reported that 68% of UAS mishaps involved causal human factors and Williams (2004) reported that 67% of Predator mishaps involve human factors. Some researchers looked at Class A (more than $1 million damage or a fatality), B (more than $500,000 damage, and C (more than $20,000 damage) mishaps (e.g., Tvaryanas, 2006), some considered Class A mishaps only (Williams, 2004), and others did not specify the scope of the mishaps analyzed.

Experience with previous efforts to reduce mishaps in manned aircraft dictates that successful interventions to improve reliability must be based on an accurate understanding of the root causes leading to failure. Several researchers recently documented differing root cause patterns across organizations and platforms. Helmreich, Wilhelm, Klinect, and Merritt (2001) studied threats to safety and the nature of errors in three domestic air carriers in the United States, and observed striking differences among these airlines regarding both threats to safety and operator errors despite obvious commonality with respect to mission and environment. Nullmeyer, Stella, Montijo, and Harden (2005) reported differing mishap root causes across Air Force manned aircraft types. Williams (2004) reported major deviations in root causes across UASs, and Tvaryanas, et al. reported significant differences among root causes depending on the service involved.

Based on rapidly increasing UAS operations in both military and civilian organizations, the emphasis from senior military leaders on reducing UAS mishaps, and the lack of consensus in the literature on causal factors, we felt that root cause analyses with known parameters were needed to assess the role that training interventions could play to reduce mishaps and increase capability for a given platform. Our focus in this paper is on root causes and other characteristics of Air Force Predator Class A mishaps. This focus was chosen in part because Class A mishap reports are more detailed than Class B or Class C mishap reports, and in part because Class A mishap counts have become a highly visible metric of safety and reliability. Based on the patterns that emerged from our analyses, training interventions are proposed to address the areas of greatest potential.

Nullmeyer, Herz, Montijo and Leonik (2007) analyzed findings from all Air Force Predator Class A mishaps that had occurred from the introduction of this system into the Air Force inventory in 1995 through the end of FY 2006 to identify training-related trends. Substantial changes were reported over time regarding annual mishap rates, annual mishap counts, and causal factors. Mishap rates across the past three years were consistently less than one half the combined rate across earlier years. Mishap *counts*, however, steadily increased, as did Predator flying hours. Early mishap reports typically cited mechanical problems and operator station design issues. From 2003 through 2006, 80% of mishaps cited causal human error factors. Equipment interface problems were still cited as causal or major contributing factors in almost half of these mishaps. More specifically, mishap reports from 2003-2006 often cited shortfalls in skill and knowledge (checklist error, task misprioritization, lack of training for task attempted, and inadequate system knowledge), situation awareness (channelized attention), and crew coordination.

Based on the findings of Nullmeyer, et al., crew resource management training was developed for both the Predator formal school and for continuing Crew Resource Management training that was given to mission qualified crews. The focus of the new courseware was having students understand the primary threats to safety in the Predator community and providing techniques to manage the types of operator error that were repeatedly cited in Predator mishap reports. The remainder of this paper updates previous findings regarding human factors trends in Predator mishaps, focusing on publicly accessible information.

Methods

The United States Air Force Judge Advocate General's office maintains an online repository of Accident Investigation Board (AIB) report summaries for Air Force Class A mishaps. This site (http://usaf.aib.law.af.mil) is publicly accessible, lists Class A mishaps by fiscal year across all platforms in the Air Force, and provides one page executive summaries of AIB reports as they are released. These summaries describe the mishap and discuss probable cause. Most, but not all Class A mishaps are analyzed by an AIB. The publicly accessible database accounted for over 90% of all Class A Predator mishaps.

The Air Force Safety Center generates mishap investigation reports for every Class A mishap and provides results at varying levels of granularity. The analyses reported here provided the structure for further analyses of information from three distinct Safety Center sources that were used to guide changes in mishap reduction training. Moving from general to specific, the first was statistical data from the Air Force Safety Center web site (http://afsafety.af.mil). These data include hours flown and numbers of Class A mishaps by fiscal year and by aircraft type. The second data source was safety investigation summaries. These provide a brief narrative of the mishap, and categorized the Predator Class A mishaps as being primarily logistics-, maintenance-, or operations-related. Summaries also provide descriptive data for each mishap such as phase of the mission and time of day in which the mishap occurred, and list conclusions and recommendations. The third Safety Center source used was discussions of human factors from the full mishap investigation reports. Safety Investigation Board (SIB) findings are formally documented as a section of the full mishap report. These findings were reviewed for descriptions of human factors causing or contributing to the mishap. In addition to the board findings, a separate Life Sciences Report is prepared by the Life Sciences Branch of the Air Force Safety Center. The Life Sciences Report provides a chronological mishap narrative and a discussion of every element cited in the human factors database. Interrelationships among the human factors may be addressed.

AIB summary reports (http://usaf.aib.law.af.mil) were initially analyzed to generate descriptive trend data regarding mishap frequencies and the general nature of the mishaps (equipment failure or operator problems) over time. Flying hour data were obtained from the Air Force Safety Center web site (http://afsafety.af.mil). Data from both sources were combined to generate mishap rates.

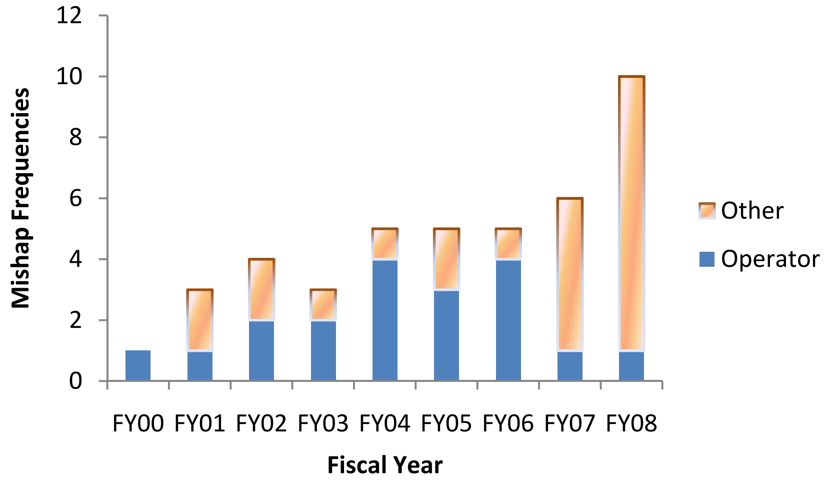
Four training-related problem areas emerged from analyses of the full and more detailed Safety Center mishap reports: (1) situation awareness development and maintenance, (2) task management, (3) decision making, and (4) crew coordination. Legacy Crew Resource Management (CRM) training for both initial qualification training students and recurrent training for qualified operators was refocused on these four areas and on Predator operations. This new training continued to be accomplished in a seminal format, but content and case studies were updated to emphasize Predator-specific threats to safety that are under the control of crews and strategies to mitigate the types of crew error that have led to Class A mishaps.

Results

Baseline Predator mishap frequencies increased systematically over time as shown in Figure 1 (http://usaf.aib.law.af.mil, 2009). Fiscal years accounted for over 65% of the variability observed in mishap frequencies (correlation = .81, $p < .001$). Causes in AIB reports are most usually stated in terms of a single "clear and convincing" cause. As part of our analyses, this cause was categorized as being either operator error or some other factor, usually equipment failure. The primary cause of the mishaps appeared to be shifting toward operator error problems over time through FY 2006. Three Class A Predator mishaps that predated the AIB databases. Two of these three were attributed somewhat evenly between equipment failure and operator error. Mishaps in the early years (FY 1998 - 2003) were most often attributed to equipment failure. Mishaps from the next three years (FY 2004 – 2006) were attributed primarily to operator error.

Safety Center Class A reports provide more detailed descriptions that address multiple causal and contributing factors and the interactions among them. In the detailed Safety Center analyses, nine of 15 mishaps from FY 1997-2003 were attributed to equipment factors, and even four of the six operator-error mishaps cited causal equipment interface problems. In total, thirteen of the fifteen mishaps from 1997 through 2003 cited causal equipment factors. In FY 2003-2006, one mishap was attributed primarily to equipment failure and the remaining 14 were attributed to operator (12 mishaps) or maintainer (2 mishaps) error. Further, only three of the 12 mishaps attributed to operations

Figure 1: Predator Class A Mishap Frequencies by Fiscal Year (http://usaf.aib.af.mil)

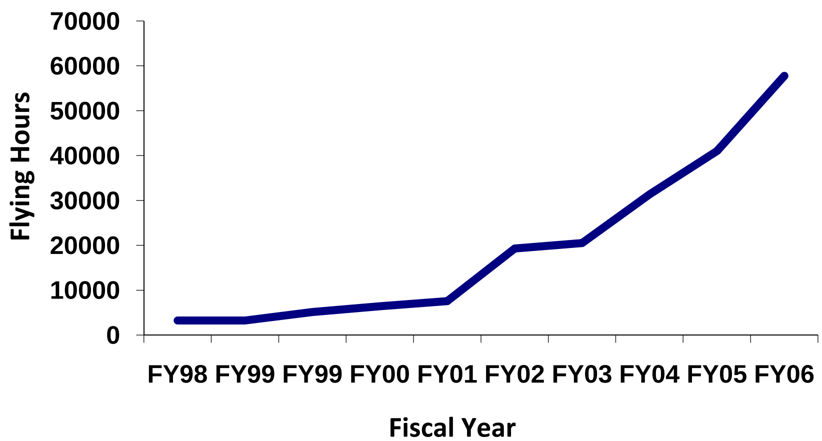


cited equipment as a causal factor. Functional design continued to be cited as a contributing factor, however, in many of these recent mishaps.

Mishap frequencies after training modifications that were introduced at the end of FY 2006 continued to rise in FY 2007 and 2008, Twenty six mishaps occurred between 2000 and 2006, averaging 3.7 per year. Sixteen additional mishaps occurred between 2007 and 2008, averaging 8 per year. The AIB database revealed a substantial drop in mishaps attributed to operator error and reflected a reversal of probable cause from operator error through 2006 to other factors, almost always equipment failure, since then. A similar pattern was seen in Safety Center mishap reports (chi square = 7.61, df = 1, $p < .01$).

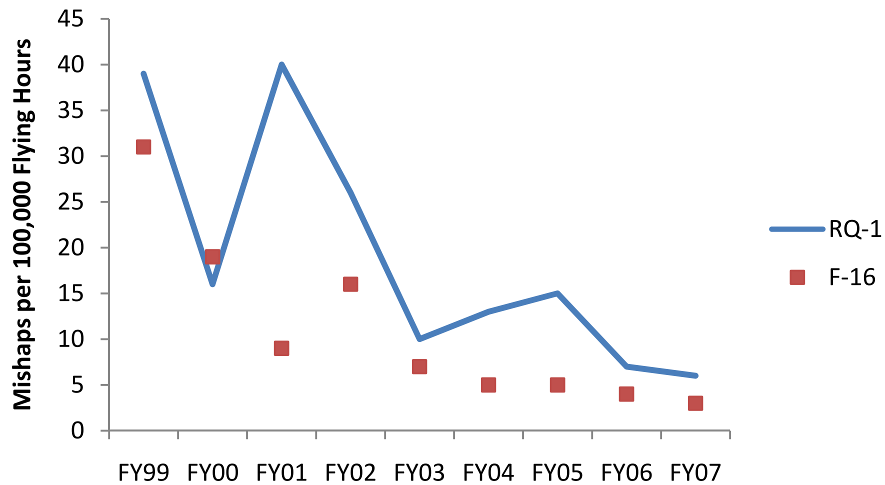
Predator flying hours are shown in Figure 2. The numbers of Predator mishaps clearly need to be interpreted in the context of the accelerating growth of flying hours are reported on the Air Force Safety Center Web site (http://afsafety.af.mil). Annual flying hours increased from less than 3000 in FY 2000 to almost 80,000 in FY 2007, the latest year reported. Projections call for continuing increases in UAS operations. These changing utilization levels are important to consider when interpreting trends in mishap frequencies over time.

Figure 2. Predator Hours Flown Annually from 2000 – 2007



Mishap rates per 100,000 flying hours help take into account the rapidly growing utilization of Predators and provide a better metric of safety then frequencies. Figure 3 depicts both Predator and historic F-16 mishap rates starting with the first year in which more than 5000 hours were flown annually in either platform. With rapidly increasing operations, mishaps per 100,000 flying hours decreased substantially since the early 2000's despite increasing mishap counts. Comments from some of the early reviewers suggesting unusually high mishap rates in UASs were based on the early years, when mishap rates were high. Over time, Predator mishap rates are following a pattern that is very similar to the rates seen early in the history of the F-16 weapon system. Both systems encountered mechanical and human error problems early in their life cycles. F-16 mishaps are now very close to overall Air Force mishap rates. For F-16 mishaps, the data points represent the time period between 1977 and 1984. Predator Class A mishap rates were about 6 per 100,000 flying hours in 2007 and are projected to be close to 10 per 100,000 flying hours in FY 2008. For comparison purposes, the overall Air Force Class A mishap rate has been slightly less than two mishaps per 100,000 flying hours for the past decade.

Figure 3: RQ-1 (Predator) and F-16 Class A Mishap Rates (with Historic F-16 Rates FY 77-85)



Conclusions

Predator mishap trends reflected systematic and substantial changes over time. The overall direction of these trends depends on the measure used. Mishap frequencies steadily increased over time as have Predator hours flown. Mishap rates per 100,000 flying hours decreased substantially (from 23 Class A mishaps per 100,000 flying hours from fiscal years 1997-2003 to less than 11 in fiscal years 2004-2007). Despite the decrease, Predator mishap rates remain high relative to more mature Air Force weapon systems, but they are similar to the rates seen in the early years of F-16 operations and are dropping quickly.

In FY 2004-2006, a substantial increase was observed in mishaps that cited insufficient operator skills and knowledge. The threat and error management model (Helmreich, et al, 2001) is widely used by air carriers to enhance safety. We believe that it also provides a reasonable structure for improving UAV mishap rates in military operations and ultimately for increasing combat capability. A key part of this approach is to use evidence to structure interventions to alleviate the specific problems that actually plague a particular community. Training is one of several tools that can be used to meet safety and capability objectives, but other changes such as equipment modifications and altered procedures may also be integral parts of an effective overall error mitigation strategy. The bottom line is that the better we understand the real threats to safety, the more successful we are likely be in developing effective strategies to mitigate them. With the recent rise in equipment-related problems, it would be prudent to address the role of human error in equipment maintenance and if warranted, develop threat and error management training for maintainers. Following the effort to refocus CRM training to address known threats to safety, overall mishap rates continued to climb, but the causes cited in AIB reports shifted from human error to equipment failure. Similar patterns were apparent in the more detailed Safety Center mishap reports.

To substantially increase the numbers of Predator operators, the Air Force is currently evaluating alternatives to using experienced pilots to control Predator platforms. Two programs are underway, one looking at the ability of pilots who recently completed undergraduate pilot training and another assessing the ability of non-pilot candidates to perform the tasks required of Predator pilots. One measure of merit is mishap rates. It is clear that mishap frequencies, rates and causes are all dynamic in the emerging field of UAS operations, and that mishap reports provide a fertile source of insight into where training and operations need to be improved. Our analyses suggest that raw frequencies could be misleading, especially in light of few operator error mishaps in the past two years. Instead, safety analyses for the purpose of assessing crew performance need to focus on mishaps where operator error is a factor.

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